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DATE: 5/16/13

HYDRO GEO CHEM, INC.

Groundwater Consultants

1430 N. Sixth Avenue
Tucson, Arizona 85705
(602) 623-6981

18 April 1985

Mr. Ron Solimon
Pueblo of Laguna
P.O. Box 194
Laguna, New Mexico 87026

Dear Mr. Solimon,

Enclosed please find five copies of our final report on the monitoring program and Jackpile Mine reclamation assessment. There are a few clarifications and editorial changes, but it remains substantially unchanged.

Please get in touch with me anytime if you require elaboration or to disucss any future work. As always, it has been a pleasure doing this work for the Trible.

Sincerely yours,

John J. Ward
Project Chief

Enclosures: Monitoring and Reclamation Assessment (5 copies)

PUEBLO OF LAGUNA
RECEIVED
MAY 03 1985
OFFICE OF THE SECRETARY

RECEIVED
APR 22 1985
Pueblo of Laguna
Legal Assistant

WATER QUALITY AND MINE RECLAMATION EVALUATION
PUEBLO OF LAGUNA, NEW MEXICO

FINAL REPORT

Submitted to

PUEBLO OF LAGUNA
P.O. BOX 194
LAGUNA, NEW MEXICO 87026

By

HYDRO GEO CHEM, INC.
1430 NORTH SIXTH AVENUE
TUCSON, ARIZONA 85705

April 15, 1985

WATER QUALITY AND MINE RECLAMATION EVALUATION
PUEBLO OF LAGUNA, NEW MEXICO

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EXECUTIVE SUMMARY

The purposes of this study were to review and analyze the Pueblo water quality monitoring program, to furnish necessary equipment and training to Tribal personnel for an ongoing monitoring program, to analyze existing water quality data for evidence of contamination, and to review existing reports on the proposed reclamation plan for the Jackpile-Paguate mine.

Monitoring Program

The present monitoring program is being conducted by the Tribe on the Rio San Jose, Rio Puerco, and the Rio Paguate - Rio Moquino system above and below the mine. In addition, Anaconda monitors surface and groundwater within the mine site. There is some overlap in the two programs. Analyses on the Rio San Jose and around the mine site were examined for quality and for spatial and temporal trends. In general, the quality of the analyses collected since 1983 is lower than previous analyses. Only 57 percent of the analyses had an acceptable (less than 5 percent error) cation-anion balance. The possible sources of error are in reporting and data transfer (typographical), in serial dilutions (systematic), and in sample collection and preservation. It is recommended that the Tribal monitoring people perform quality checks upon receipt of the lab reports. Three such checks are 1) establish that TDS falls within a certain fraction of the specific conductance, 2) perform cation-anion balances, and 3) plot chemical constituents against time so that the variations in the constituents can be established and used to check for anomalous values. To improve the quality of the program it is recommended that at least one sample in ten be taken as a duplicate for analysis. The agreement between duplicates should be within 10 percent. In addition, laboratory documentation describing analytical methods, equipment, and the precision and accuracy of procedures should be obtained. It is also recommended that the sampling interval be cut back to once per month, and that, eventually, a small flow meter be purchased to be used in conjunction with stream sampling.

The interpretation of analyses from the Rio San Jose revealed no temporal trends in any of the major constituents. Nitrate, however, shows an increasing trend at one station (Seama) between 1967 and 1979. The 1983 analyses show higher concentrations of boron and nitrate at all stations. However, the constituents increase downstream, away from the Grants Sewage Treatment Plant. This suggests that there is a source of nitrate to the stream from within the Pueblo. However, the scatter in the data may imply that the analysis is not precise at these low nitrate concentraions (1 to 3 mg/l).

Similarly, no temporal trends in major constituents were identified in the Rio Paguate or Rio Moquino analyses, which may only be due to the short time record. There is good spatial correlation, as expected, showing the deterioration of water quality through the mine site. Continued monitoring is critical in these stream reaches to assess time correlations before and during the reclamation period. We recommend that the tribe take over three of Anaconda's stream monitoring sites upon cessation of that company's activities. Also, water level and groundwater chemistry analyses collected by Anaconda should be examined to aid in deciding at which mine-site wells monitoring should be continued.

Reclamation Assessment

The predicted groundwater recovery levels as well as the predicted changes in groundwater chemistry are critical concerns in the determination of the final backfill grades and materials. We evaluated the Anaconda computer model and predictions in this regard, and believe that, in general, their evaluation underestimated the final groundwater recovery levels in the backfill, the amount of water flowing through the pits, and the amount of water quality degradation.

These values are underestimated because of the manner in which the Jackpile sandstone and backfill materials are treated in the model. The amount of flow through the Jackpile was estimated as 66 gpm in the model. However, because the aquifer is not in steady state, water is in reality lost from the aquifer in ways not considered in the model, such as through pumping and evaporation losses. This could cause an error of 100 percent or more in the computed flow. Related to this are the values for Jackpile permeability used in the model. Other evidence, not used in the model, supports higher permeability in the Jackpile.

The predicted groundwater recovery levels in the pits are very sensitive to the values chosen for permeability of the backfill material. Because of the emplacement techniques, the actual backfill permeabilities should show a very large range. However, high permeability layers should not have great lateral continuity, so that the effective permeability of the backfill material as a whole is low. The modeled permeability value of 190 ft/day is excessively large, and causes the modeled groundwater recovery levels to be too low.

WATER QUALITY AND MINE RECLAMATION EVALUATION
PUEBLO OF LAGUNA, NEW MEXICO

I. INTRODUCTION

This study was conducted on behalf of the Pueblo of Laguna, New Mexico, by Hydro Geo Chem, Inc., under Tribal Resolution 70-38. The purpose of this study was to evaluate Tribal monitoring programs and Jackpile-Paguate Mine reclamation plans. The specific tasks were

1) To review and analyze the Tribal water-quality monitoring program, consisting of an analysis of existing data for precision and accuracy; a determination from these analyses of the possible presence and migration of effluent disposed by the City of Grants into the Rio San Jose; and a determination of the presence and migration of chemical and radiological pollutants from activities on the Anaconda lease.

2) To review existing reports on the environmental assessment of the Jackpile-Paguate Mine, especially those concerning prediction of post-recovery water levels and changes in water chemistry.

3) To furnish equipment for the water-quality sampling program and to establish personnel training for an ongoing monitoring program.

II. BACKGROUND

The Pueblo of Laguna is located about 40 miles west of Albuquerque along the southeastern edge of the San Juan Basin. The discovery of uranium ore in the Basin in the early 1950's has led to intense mining and related development. This has subsequently taxed the water resources of the area, both through water consumption from mining, milling, and related uses, and through decreases in water quality.

The Pueblo is affected by these activities in several ways. Most important are the impacts from mining at the Jackpile-Paguate Mine and from sewage effluent released by the Grants Sewage Treatment Plant (STP). Currently of less importance, but still of long-term concern, is the lowering of groundwater levels in the Jurassic aquifers from mine dewatering.

Anaconda Minerals, which has ceased mining at the Jackpile, has proposed a mine reclamation plan (Anaconda Minerals Company, 1982) designed to mitigate some of the adverse environmental impacts and to partially restore the disturbed area. Anaconda contracted with Dames and Moore to provide predictions of the post-recovery groundwater levels and water-quality impacts (Dames and Moore, 1983). In addition, the U.S. Department of the Interior is presently conducting an environmental impact assessment of the various proposed reclamation alternatives. Part of this assessment was an evaluation of the radiological impacts of each reclamation alternative by Argonne National Laboratory (Momeni and others, 1983). The draft environmental impact statement (PDEIS) is in preparation.

The Grants-Milan-Bluewater municipal areas have discharged sewage with various degrees of treatment into the Rio San Jose since at least the mid-1950's. The effect of this effluent on water quality in the Rio San Jose on the upstream Acoma Reservation has been documented by Aqua Science, Inc. (1982). The effects on the Rio San Jose within the Laguna Reservation is discussed below.

III. MONITORING PROGRAM

Monitoring Objectives

The general Tribal objectives of the water-quality monitoring program are to protect the actual and attainable water resources of the Pueblo, including the Rio San Jose and its alluvial aquifer, and the Rio Paguate drainage system, from man-caused pollution. Specifically, the Tribe should not suffer damages from the effects of sewage effluent in the Rio San Jose, nor from the effects of mining and reclamation of the Anaconda lease on the Rio Paguate. A program designed to insure that Tribal objectives are met should

1) determine those particular parameters (physical or chemical) which are indicative of pollution;
2) determine flow paths for these pollutants;
3) sample along flow paths at appropriate temporal and spatial intervals to determine:
   a) the existence of the pollutant
   b) pollutant attenuation
   c) base-line water quality;
4) integrate results of the program into those conducted by other agencies;
5) provide for timely notification of authorities if violations occur.

We outlined such a program for the Rio San Jose and Rio Puerco in a previous report (Hydro Geo Chem, Inc., 1982). Because of ongoing reclamation studies on the Anaconda lease at that time, the area around the lease was excluded from the monitoring plan. The program has since been expanded to include this area.

Existing Programs

To our knowledge the following programs are or were in effect for the Rio San Jose and Rio Paguate drainages:

1. The New Mexico Environmental Improvement Division (EID) has collected water-quality information at seven stations along the Rio San Jose, Rio Paguate, and Rio Moquino above and below the Jackpile-Paguate Mine. Since about 1982 EID has ceased sampling around the Mine area, but maintain three sampling locations between Grants STP and the upstream Acoma boundary.

2. The USGS has compiled most of the other water quality information up to about 1980 that had been collected by the USGS, BIA, or the Tribe (Lyford, 1977; Risser and Lyford, 1981). Sampling stations were

1) Rio Paguate above the town of Paguate,
2) Rio Paguate below Paguate Dam (Quirk Reservoir),
3) Rio San Jose at Seama Diversion,
4) Rio San Jose at Casa Blanca Diversion,
5) Rio San Jose at New Laguna Dam,
6) Rio San Jose at Mesita Diversion,
7) Rio Puerco at I-40 bridge (one sample).

The USGS ceased collecting water-quality samples after mid-1979; they maintain continuous flow records on the Rio San Jose at Horace Springs, Rio San Jose at Correro, and Rio Paguate below the Jackpile-Paguate Mine (Station 08349800).

3. Anaconda Minerals Company has since 1977 collected water-quality data at five locations on the Rio Paguate and Rio Moquino within and upstream of the mine area. They also monitor water levels in 32 piezometers constructed in the Jackpile sandstone or backfill materials, and water quality from 11 of these

piezometers.

4. A tribal monitoring program began in March, 1983. (No samples were collected on the Rio San Jose within the Reservation between 1980 and 1983.) Nine surface-water sites are sampled by the Tribe on a twice-monthly basis. These are

1) Rio San Jose at Casa Blanca Diversion (Tribal Site SJ-1, same location as earlier USGS or BIA sampling site),

2) Rio San Jose at New Laguna Dam (Tribal Site SJ-2, same location as earlier USGS or BIA monitoring site),

3) Rio San Jose at Mesita Diversion (Tribal Site SJ-17, same location as earlier USGS or BIA monitoring site),

4) Rio Paguate above Jackpile-Paguate Mine (Tribal Site PA-16, near location of Anaconda Monitoring Site S-43),

5) Rio Moquino above Jackpile-Paguate Mine (Tribal Site RM-4, about 1 mile upstream of Pueblo boundary and EID monitoring site and Anaconda Monitoring Site S-42),

6) Rio Paguate below Jackpile-Paguate Mine (Tribal Site SJ-3, same location as USGS streamflow station 08349800),

7) Rio Puerco above confluence with Salado Creek (Tribal Site RP-7, new monitoring site),

8) Rio Puerco below confluence with Salado Creek (Tribal Site RP-6, new monitoring site),

9) Salado Creek near Section 29 crossing (Tribal Site SC-5, new monitoring site).

Evaluation of Water Quality Analyses

Three hundred five analyses were examined for accuracy, temporal and spatial trends, and other correlations from 8 sampling locations, 4 on the Rio San Jose, and 4 on the Rio Paguate-Rio Moquino. The analyses were dated between 1961 and 1983. Of these analyses, 116, or 38 percent of the total were collected during 1983 by the Tribe and analyzed by the BIA Natural Resources and

Engineering Lab in Gallup. It is not known which lab(s) analyzed the earlier samples.

Statistical summaries (sample mean, standard deviations, maximum, minimum, number of samples, linear regressions), were compiled and used to determine trends. Also examined were ionic charge balances which give an indication of the laboratory analytical quality. Because the large number of samples collected during 1983 would tend to dominate correlations, we analyzed each set of data both separately and together.

Ionic species should balance to within ± 0.05. Table 1 lists the number of samples at each sampling location that met this criteria.

While a satisfactory ionic balance does not guarantee that the analysis is accurate, a poor balance indicates that the analysis is not accurate. The low number of good ionic balances in the 1983 analyses (57 percent) is disturbing. We examined the 1983 lab reports and charge balances and several patterns seemed to emerge. Possible reasons for inacurate analyses are given below.

Table 1: Number of chemical analyses with acceptable ionic balances (within ± 0.05)

Location	Prior to 1983	1983
Rio San Jose at Seama Diversion	37 of 44, 84%	None Collected
Rio San Jose at Casa Blanca Div.	36 of 41, 88%	8 of 19, 42%
Rio San Jose at New Laguna Dam	8 of 10, 80%	9 of 16, 56%
Rio San Jose at Mesita Diversion	34 of 37, 92%	12 of 18, 67%
Rio Paguate above Jackpile Mine	12 of 15, 80%	12 of 21, 57%
Rio Paguate below Jackpile Mine	14 of 17, 82%	16 of 21, 76%
Rio Paguate below Paguate Dam	9 of 9, 100%	None Collected
Rio Moquino above Jackpile Mine	14 of 16, 88%	9 of 21, 43%
Totals:	164 of 189, 87%	66 of 116, 57%

1. Typographical errors. It seemed in numerous instances that some values were one order of magnitude too large or small (ie., reported as 120 instead of 1200). Other analyses may have had values switched around. This type of error may have been typographical.

2. There were more instances of the cation sum exceeding the anion sum than the opposite. This may indicate a systematic analytical problem, such as errors resulting from serial dilutions. Sulfate, because of its high

concentration in most analyses, may be the source of some of the errors.

3. Analyses with poor balances were often grouped around certain dates. Suites of samples are collected within one or two days, and the analyses are usually reported on one day for a particular suite. This may indicate some sporadic analytical problem.

4. Calcium, magnesium, and sulfate are the ions that seemed to show the most scatter for a particular sampling site. There were several instances of a reversal in the calcium-magnesium ratio, and sulfate occasionally varied as much as an order of magnitude. These may be typographical errors. Errors may also be due to inadequate sample collection and preservation techniques, which could have caused complexing or precipitation, although this does not affect the cation-anion ratio.

Appropriate field-collection procedures are very important in insuring high-quality analyses. In the fall of 1983 we conducted a training program in field procedures and field equipment care and use. Parameters that are now measured in the field are temperature, conductivity, and pH. Samples are field-filtered, and one split is acidified to prevent precipitation. In addition, staff gages are now installed at all sampling sites, and gage heights are recorded during sample collection.

Because of the analytical and man-power costs involved in this program, and because of the importance of high-quality chemical analyses of Rio San Jose and Rio Paguate water in determining the effects from sewage effluent and mining-reclamation, we believe certain steps should be taken by the Tribe to improve the quality of the analyses. The following procedures should help in this regard.

1. The relationship between specific conductance and TDS can be used to estimate the accuracy of the TDS determination. The regressions between TDS and conductance showed three different relationships:

a) For Rio San Jose water TDS/conductance averages 0.75. For high TDS values (greater than 3000 mg/l) the ratio averages 0.83. For low TDS values (less than 1000 mg/l), the ratio averages 0.69.

b) For Rio Moquino water and Rio Paguate water below the mine, the TDS/conductance ratio averages 0.81. For high TDS values (greater than 2500 mg/l) the ratio is 0.91 and for low TDS values (less than 750 mg/l) the ratio is 0.68.

c) For Rio Paguate water above the mine the correlation is only fair. This is probably due to the low TDS and possibly higher fraction of non-ionized solutes in the water. The TDS/conductance ratio averages 0.69 and ranges between 0.67 and 0.92.

The procedure first requires that the field-measured conductance value be standardized to 25°C. This is accomplished either by measuring conductance after raising the sample temperature to 25°, extrapolating the 25° value from measurements at several other temperatures, or with the relationship:

$$25^\circ \text{ Conductivity} = \frac{\text{Measured Conductivity}}{1 + 0.02(\text{temp}(^\circ\text{C}) - 25)}$$

2. Ionic balances should be performed on all analyses soon after receipt of the lab reports. The procedure for these calculations was given in an earlier report. If the ionic balance does not agree within ± 5 percent, the lab should be notified, the lab report checked for typographical errors, and the sample re-analyzed for the suspected incorrect constituent values. If neces-

sary, the site should be resampled.

3. A critical aspect of quality control is the reproducibility of the analytical results. Analytical agreement among duplicate samples is one way to determine this reproducibility. We recommend that at least one duplicate sample in ten be taken. The differences between results should be less than 10 percent for each constituent. If the lab maintains this precision over many duplicates, then we can be assured that reproducibility is good. To insure that the lab does not know which samples are duplicates, sample bottles should be numbered or lettered with no reference made to sample location. Either a consecutive or random numbering scheme should be used.

4. Documentation of the lab's internal quality control should be requested. Specifically, they should send a list of their analytical techniques, equipment, and their expected accuracy and precision for each constituent.

5. Consideration should be given to purchasing a flow meter (pygmy meter) for use when sampling. Flow measurements can be used to establish a rating curve for the staff gages, which is critical to the computation of solute loads in the streams.

6. The present sampling interval of every two weeks seems excessive. It is probable that little additional information can be gained with this close sampling interval. Sampling intervals should be changed to once per month for the following year, and eventually to 6 times per year.

7. Time-series plotting of the chemical data should proceed on a regular basis. These plots are valuable so that trends can be identified and extraneous values noted, and so that the information can easily be presented to other groups. We recommend that plots be made of gage height, flow rate (if available), TDS, conductivity, sodium, chloride, sulfate, nitrate, boron, and phosphorous.

Rio San Jose Analyses

The conclusions reached in our 1982 report on the water quality in the Rio San Jose and Rio Paguate have not changed with the incorporation of the 1983 analyses into the data base. Except for nitrate at one station, we were not able to identify temporal trends in any of the constituents. Spatial trends were usually regular and could be tied to patterns of groundwater inflow.

The parameters of interest in the Rio San Jose are those which might be associated with sewage effluent. These are total dissolved solids, specific electrical conductance, chloride, sulfate, nitrate and boron. Table 2 shows average values for these constituents at the four Rio San Jose stations.

Table 2: Average chemical analyses for Rio San Jose stations

Constituent		Seama	Casa Blanca	New Laguna	Mesita
TDS	(mg/l)	2127	1391	1359	1871
Cond.	(μmhos)	2781	1937	1895	2467
Cl	(mg/l)	214	144	150	178
SO_4	(mg/l)	884	583	548	854
NO_3	(mg/l)	1.73	2.10	2.86	1.33
B	(mg/l)	.52	.75	1.25	.89

The major constituents indicate a regular improvement in water quality between Seama and New Laguna Dam. This is due to the inflow of groundwater from the Jurassic-Cretaceous system, as was first identified by Lyford (1977). Between New Laguna Dam and Mesita the water quality decreases, probably due to the water picking up constituents from the Triassic rocks that the stream flows across, and from Rio Paguate inflow. The Seama station, however, has the lowest water quality of the four Rio San Jose stations, in terms of the major constituents. In terms of the major constituents, no time correlation could be found.

The distribution of nitrate and boron suggest that there is a source of these constituents between Seama and New Laguna Dam, possibly from sewage inflow on the reservation. This distribution, however, may be due to sampling distribution. Because the Seama station is presently not being monitored, no 1983 data are available. However, nitrate concentrations at the other three stations were highest during 1983. Furthermore, from 1967 to 1979 there was a fair time correlation with increasing nitrate at the Seama station (correlation coefficient, r^2, = 0.54), but not with boron over the same time period. There is no correlation between time, boron and nitrate at the other three stations (both with and without the 1983 data). The only conclusion that can be reached is that there was an increase in nitrate at the Seama station up to 1979. The high nitrates at the other three stations indicate either that there is a source of nitrate to the stream from within the reservation, or that there are laboratory analysis problems. We recommend that both of these possibilities be checked.

Rios Paguate and Moquino Analyses

The record available to us for the Rio Paguate and Rio Moquino is from 1976 to 1983, except for the Rio Paguate below Paguate Dam, which runs from 1976 to 1979. Anaconda chemical analyses are not available. In the Rio Paguate and Rio Moquino important parameters are TDS, sulfates, chlorides, nitrates, boron, and uranium. Table 3 lists average values for some of the important chemical constituents.

Table 3: Average chemical analyses for Rio Paguate and Rio Moquino

Constituent		Paguate Above Mine	Moquino Above Mine	Paguate Below Mine	Paquate Below Dam
TDS	(mg/l)	557	1348	1616	2092
Cond.	(µmhos)	811	1676	1944	2311
Cl	(mg/l)	14	13	18	30
SO_4	(mg/l)	184	720	869	1215
NO_3	(mg/l)	1.03	1.10	1.06	-
Boron	(mg/l)	.89	1.05	1.01	-
U	(µg/l)	1.6	37	157	-

Regressions of these constituents showed no correlations with time which was expected because of the short period of record. We can see from this table, however, the significant downstream deterioration in quality. The analyses of water below Paguate Dam indicate that the deterioration in Rio San Jose water at Mesita could in part be caused by the Rio Paguate.

Degradation of Rio Paguate water quality is discussed in several publications (Lyford, 1977; Hydro-Search, 1979; Hydro Geo Chem, 1982). Unresolved issues are whether mining activities contributed to this deterioration, whether the Rio Moquino is the primary contributor of poor water, or whether it is caused by groundwater discharge near the confluence of the two streams. Determination of the time-dependence of these constituents and others, such as suspended and bed-load materials, will assist in separating the mining and reclamation effects from the natural processes.

We recommend that the three surface water stations presently being monitored by the Tribe be continued. Although there is some duplication with Anaconda's monitoring in this area (See Table 5.2-1 in Anaconda Minerals, 1982, for locations of their sampling points.), we may find useful correlations and detect analytical problems once both data bases are compared. Upon the cessation of Anaconda's monitoring activities, we recommend that sampling be maintained at their sites S-46 (Rio Paguate above confluence), S-47 (Rio Moquino above confluence), and S-45 (Mesita, or Paguate Reservoir). Staff gages, similar to the ones previously installed by the Tribe, should also be installed at these sites.

Anaconda also measures water levels in some 32 piezometers within the mine site, and collects samples for chemical analyses (twice yearly) from 11 of them. We recommend that the Tribe obtain these data and data plots, if available, or plot and compare the water levels and chemistry. From these records, certain wells may be recommended for continued monitoring.

IV. MINE RECLAMATION ASSESSMENT

The reclamation plans as proposed by Anaconda call for backfilling the open pits to a level three feet above the projected groundwater recovery level, buttressing and scaling pit walls, modifying dumps to promote stability, and revegetating areas for livestock forage and erosion control (Anaconda Minerals Company, 1982). The mining company contracted Dames and Moore to provide predictions of the post-recovery water levels, time to recovery, and the quality of water that would eventually emanate from the pits (Dames and Moore, 1983).

Our critique of their evaluation is divided into a section on general comments, covering the conceptual model, structure, and documentation of results; and a section on specific comments, covering input parameters, boundaries, and chemistry.

General Comments

Dames and Moore (1983) modeled the Jackpile sandstone as a two-dimensional system bounded by impermeable layers (the overlying Dakota and underlying Brushy Basin). Modeled flow in the system was from the north and northwest to surface discharge areas along the Rio Paguate drainage and to areas of evaporation along outcrops. Because the Jackpile outcrops are discharge areas, recharge occurs interformationally from the overlying Oak Canyon Member of the Dakota Sandstone.

Despite the complexity of the mathematical formulation and computer codes used to describe groundwater flow, little is actually known about the hydrologic characteristics of the Jackpile sandstone that are input to the model. Boundary conditions, recharge rates, and aquifer parameters into the model must be estimated for each model node. It is impossible to accurately place all the correct values in all of the model nodes, however, because they are simply not known. These uncertainties give rise to model error.

Uncertainties can be dealt with in several ways. One is to assign "conservative" values to the parameters, and thus strive for a conservative or worst-case prediction. The problem with this approach is that a so-called conservative value may affect both the modeled flow and head values. So although modeled heads may be higher, modeled flow may be much lower. In the case of the Jackpile, this results in an underestimation of leaching effects. Dames and Moore stated that their model was conservative (page 16), because simulated pre-mining water levels were, in general, higher than measured ones. They believed that this assignment would lead to a conservative simulation of post-recovery water levels. We show below that this is not the case.

A more accurate way to test the effects of uncertainty in model parameters is to vary each parameter individually within its plausible range and run model simulations with each of these variations. The change in the prediction resulting from a change in a particular parameter is a measure of the sensitivity of the prediction to that parameter. If the sensitivity is small, then we can conclude that even if the parameter was poorly estimated, the prediction will not be badly affected by errors in the parameter. On the other hand, if the sensitivity is large, then errors in the parameter lead to large errors in the prediction. This type of model simulation is called a sensitivity test. Dames and Moore conducted these tests for uncertainties in the hydrologic parameters of the backfill materials. They did not, however, run sensitivity tests on the hydrologic parameters of the Jackpile sandstone for the steady-state, pre-mining conditions. Instead, a "verification" run, in which the model simulated the present-day (end-of-mining) configuration of the potentiometric surface, was used to justify the reasonableness of the aquifer parameters.

Specific Comments

1. Recharge and Discharge

The simulated recharge to the Jackpile in the Dames and Moore model was 66 gpm (page 15). This value is in fair agreement with Hydro-Search's (1979) measurements of groundwater discharge to the Rio Paguate. However, in our 1982 report we documented nearly 200 gpm of discharge from the combined Dakota-Jackpile aquifer system, or more than three times Dames and Moore's simulated flow. Their simulated flow seems much too low. By accounting for discharge to the Rio Paguate only, Dames and Moore ignored other discharge such as downward leakage, evaporation from the ponds, and to pumping wells for dust control, all derived from aquifer storage and reduction in aquifer discharge. The USGS (1982, table 14) lists numerous wells in the mine area in which water levels dropped between 1980 and 1981. They stated that much of the Jackpile flow from the west is intercepted by the north and south Paguate pits and by pumpage from the P-10 shaft, and that non-equilibrium conditions are likely to prevail over the mine area.

Dames and Moore estimate that between 0.12 and 0.24 inches of recharge occur through the desert soils over selected areas in the model. It appears that the selection of the recharge rates and areas is somewhat arbitrary. Because of the large area of contact between the Dakota and Jackpile sandstones, a larger recharge area would be more reasonable. In contrast to the recharge arguments made for the desert soils, Dames and Moore state that no net recharge would occur in the backfill because of the desert environment. We believe that the same argument should apply to both the backfill and natural soil areas, meaning that one should not use the same climatic conditions to argue for zero recharge in one case and some finite value in another. The ability of the backfill to absorb water due to its higher permeability makes it seem more reasonable to allow recharge to occur in the backfill areas. Such enhanced permeability has been observed in backfill associated with coal mining inWestern Wyoming.

We feel that a water budget should be constructed for the mine area which would help in quantifying the amount of water removed from storage in the Jackpile during mining, and estimating the reduction in discharge to the Rio Paguate. Some information could have been gained had Dames and Moore supplied mass balances over time during the verification run, and which could have been checked for reasonableness with a water budget. Not providing mass balances for any of the model runs is a shortcoming of the modeling effort.

The net effect in underestimating flow through the Jackpile is a proportional underestimation of the water levels in the backfill. Assuming that the downstream head in the backfill is fixed (controlled by the stream level), then the head in the backfill is controlled by the distance from the downstream edge, and is proportional to the backfill permeability and the Jackpile flow that enters the backfill. For example, if the modeled amount of water level recovery in the backfill is 10 feet above the stream level, doubling the modeled flow rate would raise the recovery level an additional 10 feet.

2. Permeability

The low Jackpile permeability used in the model was necessary, with the low flow rate used, to produce an adequate head match. Transmissivity used in the model ranged between 5 and 37 ft^2/day, the higher value used in only a small area. Published data indicate that the transmissivity of the Jackpile may be much higher than that used in the model. Risser and Lyford (1981, their Table 3) list a transmissivity of 410 ft^2/day for Sohio well LJ 205; the listed depth, and Dames and Moores aquifer thickness and aquifer base elevation maps (their Plates 5 and 6) place the well in the Jackpile sandstone. In addition, it was found during shaft drilling at the Bokum Marquez mine that the Jackpile sandstone produced 150 gpm (New Mexico Environmental Improvement Division, 1980). These are indications of high Jackpile transmissivities in some areas; they also show that the aquifer is very heterogeneous. Dames and Moore should have considered a larger transmissivity variation for the Jackpile.

The hydraulic conductivities measured in the backfill material ranged from less than 1 to greater than 1,000 ft/day. Dames and Moore used a value of 190 ft/day for their base simulation. A letter report defended that value (Dames and Moore, 1984), citing other studies which showed that during backfill emplacement high permeability layers develop because of material segregation. We question this justification. Over such a large area as these pits it is not reasonable to assume that highly permeable layers would have much lateral continuity. The variation in results from the hydraulic tests that were conducted in the backfill show the extreme heterogeneity expected from highly permeable layers of limited horizontal extent.

We believe that the base case value of 190 ft/day is representative of a discontinuous higher-permeability layer, and not necessarily of the backfill as a whole. We believe that the Dames and Moore cases 3.1 and 3.2, which use a backfill permeability of 2 and 20 ft/day, are more representative of the average permeability than their base case.

3. Model Boundaries

The model treated the southern Jackpile outcrop as a line of constant-head nodes that were designed to account for evaporation at the outcrop. The Rio Paguate was simulated by three constant-head nodes. The suitability of this choice of conditions is determined by the direction and amount of flow in and out of these nodes that the model calculates. If these calculated flows are consistent with measured stream flows or estimated evaporation rates, then the boundary designations are probably realistic. Because boundary flows were not documented in the Dames and Moore report, we cannot assess the accuracy with which the model treated flows in the aquifer or backfill.

4. Chemistry

Dames and Moore also modeled the predicted change in water chemistry as the backfill became saturated. The main assumption used in their analysis was that no recharge of oxygenated water would occur, and that after one pore volume had flowed through the pits, oxygen would be depleted, the reducing conditions would prevent further oxidation of minerals, and water quality would begin to approach background quality.

This simplification in the model makes the solution more tractable, and is probably a good assumption when considering those species whose solubility is controlled directly by the oxidation-reduction (redox state) conditions in the groundwater. Uranium species are an example of this. The simplification does not work as well for dissolution reactions not directly dependent on the redox state. Calcium, sulfate, and radium are common ions whose solubility is not controlled directly by the redox state. Therefore the release of these ions into solution will continue far longer than the one pore volume flow time. For these species it would have been better to model them as a continuous source (C_o = Constant).

If the flows through the Jackpile were underestimated in the model, as discussed above, then the rate of flow through the Jackpile, the time to recovery, and the distance that solutes travelled from the pits was also underestimated. This would decrease the time of arrival of solutes to the Rio Paguate and increase the volume of pollutants entering the stream.

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